Bachelor's thesis

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Effects of Aging on the Metabolic Cost of Walking in Healthy Young- and Older Adults

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Abstract

Purpose: Age related effects on the metabolic cost of walking (Cw) have been suggested by many studies to be higher in older adults (OA) than younger adults (YA). Our overview of literature investigates the relationship between aging and Cw by examining the differences between healthy YA and OA, in addition to probe the underlying age-related factors that may affect Cw. **Methods:** Using the Bibliographic databases PubMed, Oria, Embase and Web Science, eight articles were selected for thorough analysis. The selected studies consist of healthy YA- (18-35 years) and OA (59 <+ years). **Results:** By examining the 8 studies, the results showed higher Cw in OA. **Conclusion:** Walking at and around preferred speeds, all studies showed a higher Cw in the OA compared to YA. It is suggested that the age-related increase in co-contractions of antagonist muscle activation may be the reason for higher Cw in OA, but changes during chronological aging is a far more difficult issue.

Abstrakt

Bakgrunn: Det har blitt antydet fra mange studier at aldersrelaterte effekter på den metabolske kostnaden av å gå (Cw) er høyere hos eldre voksne (OA) enn yngre voksne (YA). Vår litteraturoversikt undersøker forholdet mellom aldring og Cw ved å undersøke forskjellene mellom friske YA og OA, i tillegg til å se på de underliggende aldersrelaterte faktorene som kan påvirke Cw. **Metode:** Studiene ble funnet gjennom Databasene PubMed, Oria, Embase and Web Science. Utvalget bestod av friske YA- (18-35 år) og OA (59 <+ år) uten sykdomshistorikk. **Resultat:** Resultatene fra de 8 undersøkte studiene viste alle høyere Cw i OA. **Konklusjon:** Gåhastigheter på, og rundt foretrukket hastighet, viste i alle studier en høyere Cw i OA sammenlignet med YA. Det antydes at den aldersrelaterte økningen i sammentrekninger av antagonistmuskelaktivering kan være årsaken til høyere Cw i OA, men endringer under kronologisk aldring er et langt vanskeligere problem.

Keywords: aging, metabolic cost, walking, elderly, gait, healthy.

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1. Introduction

Slow gait speed is a well-established predictor of multiple health outcomes; such as physical function, cognitive decline, disability, and death among older adults (OA) [1]. Assessing changes in gait speed over time supports tracking clinical progression of chronic diseases, establishing prognoses, and decide the treatment regimes in older patients [1]. Even if gait speed is a valid biomarker of functional and health status, used in clinical and research environments, the physiological mechanism that determine the decline in gait speed with aging are not well understood due to complex and multifaceted nature [2].

Upright bipedal walking is a central characteristic of human locomotion [3]. Based on complicated neural control system, human gait is characterized by smooth, regular, and repeating movements [4]. Walking is performed almost unconsciously and largely automatically, and several sources of information help humans to control walking [3]. The sequence for walking that occur is regulated by some form of central pattern generator, such as organization of neural circuits where proprioceptive inputs obey, leading to cyclic patterns of muscle activation [5].

Human gait is a complex task, as the body moves forward, one leg act as support while the other leg advances itself to a new support site. Then the leg reverses their roles. This series of pattern is repeated by each leg with reciprocal timing until the person's goal is reached. A single sequence of these motions by one leg is called gait cycle and consists of two phases: stance phase and swing phase [6]. The stance phase occupies 60% of the gait cycle, representing the period of time when the foot is in contact with the ground, which one leg is supporting the body mass. The swing phase occupies 40%, representing the period of time when the leg is not in contact with the ground. The gait cycle is a repetitive pattern involving steps and strides, which results in reproducible, adaptable, and efficient gait [5].

Energy efficient and inefficient gait is captured through the metabolic cost of walking (Cw). It is a measure of the rate of physiological work during walking and is usually obtained by estimation of energy consumption through oxygen uptake measurements and walking speed or distance for a given time period [7], [8], [9]. Cw is expressed by dividing gross and net metabolic rate ($J \cdot kg^{-1} \cdot s^{-1}$) by walking speed (m/s), giving energy cost per unit distance traveled ($J \cdot kg^{-1} \cdot m^{-1}$). The rate of metabolic energy consumption (e.g. watts) increases gradually with walking speed [10]. As humans varies their gait speed from slow to fast, the amount of energy consumed per unit distance has a “U-shaped” curve in relation with walking speed [11]. This is showing a minimum cost at the normal natural speed, which is the speed the normal subject spontaneously adopts (1.1 to 1.3 m/s) [8], [9], [10]. The speed is unconsciously selected by humans to minimize Cw and maximize gait efficiency [12]. Consistently, across comparative studies about species have shown that preferred speed of mobility has evolved to maximize endurance and energy efficiency [12].

Even if energy efficiency has been documented as important in describing natural and biomechanically optimal gait, OA seems to prefer slower walking speed than young adults (YA), and this slower speed also corresponds to higher Cw [13]. The mechanisms involved in this adjustment remain unclear, but with the increase of age, lower gait speeds, lower step frequencies and higher step widths is apparent in OA [14]. Furthermore, other age-related changes in Cw may be such as neurological, physiological and muscular factors [15], [16].

The purpose of this study is to provide an overview of literature on the relationship between aging and Cw, by examining the differences between healthy OA and YA. We will particularly investigate the underlying age-related factors that may affect Cw.

2. Methods

2.1 Study design

For this study we used a traditional literature study that can be defined as a comprehensive and systematic literature review of selected litterateur on the specific topic (Cw of OA and YA).

2.2 Search strategy

For our search study we used PICO-form as a review protocol. In the search we performed different Bibliographic databases such as PubMed, Oria, Embase and Web Science. Databases were searched from inception of 1995 and up to March 8. 2021. The following terms were used as index terms of free-text words: “metabolic cost” and “elderly” and “walking” and “healthy”. The search was performed using only articles posted in peer-reviewed journals. We found 133 articles in PubMed, 29 articles in Web of Science, 13 articles in Embase, with an additional “younger adult”, 13 articles in Oria. Then our process began with a headline-search, before viewing approximately 40 articles. After using our exclusion and inclusion criteria, of those 40, we chose 8 articles which were used in our study.

2.3 Inclusion and exclusion criteria

The following inclusion and exclusion criteria were defined before the articles were studied; the population of the distinct groups were an interval of YA (18-35y) and OA (59 <+ y). The individuals in those different studies had to be healthy prospects, with no history of sickness. Only studies in peer-reviewed journals were included. The measurement of value had to be the Cw, so every study that used other activities than walking was excluded. To provide an overview over age-related effect exclusively, we also excluded all data that was related to training interventions, which potentially changes the participants´ metabolic cost.

3. Results

In total 8 different studies were included. A list and summary of the included studies; participants and results are given in Table 1. and Table 2.

3.1 Participants

All studies compared OA with YA, and the mean age for OA and YA differed between studies. There was one study that only used men, Mian et al. [9], the rest had a very similar number of men and women.

Table 1. Participant’s mean age in experimental studies’

Study	**Mean age – YA ± SD**	**Mean age – OA ± SD**
Malatesta et al. [8]	25 ± 2.5	65 ± 2.5 / 80 ± 3.3
Peterson & Martin [10]	25 ± 3	71 ± 4
Mian et al. [9]	27 ± 3	74 ± 3
Dean et al. [14]	25 ± 3.6	73 ± 4.2
Floreani et al. [17]	23 ± 2.9	60 ± 3.4
Hortobágyi et al. [18]	21 ± 2.2	77 ± 4.8
Gaesser et al. [19]	26 ± 5	62 ± 1 / 66 ± 1 / 73 ± 3
Ortega & Farley [20]	25 ± 4	76 ± 4

Malatesta et al. [8] divided the population into three groups: G25y average with range; (20-29y), G65y average with range; (60-69y), G80y average with range; (77-86y), Peterson & Martin [10] (YA=25y, OA=71y), Mian et al. [9] (YA=27y, OA=74y), Dean et al. [14] (YA=25y, OA=73y), Floreani et al. [17] (YA=23y, OA=60y), Hortobágyi et al. [18] *(YA=21y, OA=77y), Gaesser et al. [19] had one group for YA and divided the OA into three groups; (YA= 26y, OA1= 62y, OA2=66y, OA3: 73y) and Ortega & Farley [20] (YA: 26y, OA=76).*

3.2 Experimental studies' methods

The original articles used in the study varied in testing and comparison of Cw. Five of the studies [9], [8], [10], [17], [20] used treadmill walking of four set speeds with no decline or incline specified, however, they recorded different variables for the physiological and mechanical response. Peterson & Martin [10]; coactivation (agonist and antagonist muscles surrounding a joint contract simultaneously to provide joint stability) indices were calculated with electromyography (EMG) and Oxygen consumption, Mian et al. [9]; mechanical and EMG, Floreani et al. [17]; mechanical work, efficiency, co-contraction time of proximal- and distal muscles, Ortega & Farley [20]; Oxygen consumption, carbon dioxide production and Step frequency, Malatesta et al. [8]; basal metabolic rate, body composition and gait (in)stability were measured by pressure-sensitive insoles placed in the subjects' shoes. Dean et al. [14] used step width as indication of (in)stability and metabolic energy expenditure. Hortobágyi et al. [18] used treadmill (0.98 m/s^{-1} speed) walk with a decline (6%) and incline (6%) and measured the neural activation of leg muscles. Gaesser et al. [19] used treadmill (1.34 m/s) and measured ventilation and gas exchange at rest and during exercise.

Table 2. Overview of conditions and findings of the included studies

Study	Age groups		Familiarized (duration)	Speed	Age effect on Cw
	OA (n)	YA (n)			
Malatesta et al. [8]	20	10	Yes (20min)	P, F, S	↑
Peterson & Martin [10]	14	14	Yes (30 min)	P, F, S	↑
Mian et al. [9]	20	12	Yes (15-20 min)	P, F, S	↑
Dean et al. [14]	10	8	Yes (10min)	P	↑
Floreani et al. [17]	16	7	Yes (15-20min)	P, F, S	↑
Hortobágyi et al. [18]	12	12	Yes (5min)	S (6% decline/ incline)	↑
Gaesser et al. [19]	94	96	Yes (30min)	F	↑
Ortega & Farley [20]	10	10	Yes (10min)	P, F, S	↑

Table 2. shows the original articles' experimental conditions and main results. Age effect on Cw: ↑ = significant higher Cw with OA (applies to all studies). Speed: P=preferred, F=fast, S=slow.

3.3 Primary findings

Without any exception, all studies showed a clearly higher Cw in OA than YA.

Peterson & Martin [10] - Found that Cw was systematically higher for OA at each walking speed and 23% higher for OA compared to YA when averaged across walking speed. Cw was also significantly affected by walking speed and showed curvilinear response with speed. OA had significantly higher coactivation in muscle around the thigh, but not in shack muscles. There were no significant age effects on time of coactivation.

Mian et al. [*9]* - Found that Cw was higher for OA by an average across speeds of 31%. There was significant difference in Cw at the slowest speed compared to faster speeds in OA than YA. The stride frequency was significantly higher in OA by an average across speeds of 9%. Thigh co-activation was moderately correlated with Cw at three speeds. Total mechanical work was not significantly elevated in OA.

*Dean et al. [14]***-** Found walking normally, OA selected wider steps and spent more energy than YA. Step lengths and step frequencies were not significantly different, although step length variability was greater in OA, in the preferred step width and energetic cost. OA walked with 41% wider steps than YA. Energetic cost was 26% higher in the OA. In the preferred step width condition, age had a significant effect on step width and energetic cost. In normal walking without external stabilization, OA walked with 41% wider steps than YA. External lateral stabilization resulted in significantly reduced step width, and subjects selected a 58% narrower step width.

Floreani et al. [*17]* - Mean values of Cw was significantly higher in OA than in YA at each speed by an overall mean of 25.1%. Furthermore, Cw changed with speed in both groups and was significantly lower at 1.11 m/s^{-1} and 1.39 m/s^{-1} than at 0.83 m/s^{-1} and 1.67 m/s^{-1}. Mean values of respiratory exchange ratio were significantly higher in OA than in YA at each speed by an overall mean of 4%.

Hortobágyi et al. [18] **-** Showed that Cw with 7% (incline) 19.2% (level) and 47.3% (decline) was higher in OA compared to YA. OA compared to YA activate their leg muscles 67.3% more during the three gait tasks. The age by condition interaction showed muscle activation was similar in incline but 115.6% (level) and 102.7% (decline) greater in OA compared to YA. Antagonist muscle coactivation was 152.8% higher in OA compared to YA.

Gaesser et al. [19] - Found that Cw were significantly higher in the OA (70y+) compared to YA. Gaesser split OA age group into three groups from 60-64y, 65-69y and 70y+, between YA and 70y+ groups they found a significant correlation between age and Cw. However, they also found considerable individual variation in Cw, with distributions that were similar for both age groups.

Ortega & Farley [20] – OA consumed an average of 20% more metabolic energy to travel a meter than YA over the range of speeds. At the speed where the net metabolic cost of transport was minimized for both groups, OA subjects consumed 17% more metabolic energy to travel a meter than YA. OA had similar step widths at all speeds but took shorter and more frequent steps at slow and moderate speeds. Ortega and Farley concluded that the higher Cw in OA cannot be explained by a difference in external work, i.e., propulsion of the body.

Malatesta et al. [8] **-** A significant effect of age was seen for Cw. This parameter was significantly higher in group 80y+ than in G25 years for all walking speeds, and mean Cw was 22% higher in G80. Cw was higher in G65 compared with G25 for two walking speeds (1.33 m/s^{-1} and 1.56 m/s^{-1}). A significant internal speed effect in the groups was observed. Cw at preferred walking speed was higher in G80 (0.229+-0.003 ml $O2*kg^{-1}*m^{-1}$) and G65 (0.205+-0.02 ml $O2*kg^{-1}*m^{-1}$), then G25 (0.179+-0.02 ml $O2*kg^{-1}*m^{-1}$). However, there were no significant correlation between gait (in)stability and Cw at preferred walking speed.

4. Discussion

The chosen literature was to provide an overview of the relationship between aging and Cw. In this report we were interested in only age and any factor that is inherent to aging. Therefore, we investigated the normal, healthy population. The main finding of the present study is that when difference between age groups is measured, there is a “change” and “increase” with age. By examining all the 8 studies, the results showed higher Cw in OA. However, the increase in energy cost is probably multifactorial, due to many factors that is inherent to aging. “Inherent” itself is an ambiguous term. OA tend to have more illnesses and health issues than YA. Some argue the contrary and point to environmental factors of living for explanation [21].

4.1 Muscular changes with aging

Gait adaptation as seen in the elderly population may be associated with the general decrease in muscle strength due to loss of motor neurons, muscle fibers and aerobic capacity [15].This loss of muscle mass together with changes in function, such as walking speed and strength is known as sarcopenia [22]. The decline in the number of muscle fibers and a reduction in muscle fiber size contribute to muscle atrophy, which can affect muscles of both upper and lower limbs [22].

It is suggested that reduction in muscle size and specific force in OA contribute to a greater metabolic stress per unit muscle resulting in recruitment of additional motor units for the given task [8], [9]. Walking at different speeds requires a higher relative intensity for OA compared to YA [10], it is proposed by Malatesta et al. [8] that a greater proportion of fast-twitch fibers, which have been shown to be less economical than slow-twitch fibers will be recruited. This is supported by that OA activated their lower-extremity muscle 67.3% more during the gait tasks [18], and the maximal isometric strength of the knee extensor muscles was inversely correlated with Cw [8]. At faster walking speeds and incline, the force developed by the lower-extremity and knee extensor muscles increased and a greater proportion of fast-twitch fibers was thus recruited.

4.2 Stability changes with aging

Aging seems to come with a reduced capacity for stability in gait, often associated with for example impaired visual and balance function [16]. It can be argued that the elderly compensates this reduction with stabilizing motor strategies that increase Cw. Considering the situations where step to step attention demands is increased due to unfamiliar terrain, such as walking on a treadmill that will present a different visual environment from overground walking. This may affect step variability and disturb the natural gait cycle [1]. By changing walking mechanics to ensure safety, OA may reduce the base of support and increase fear of falling, shortening their steps and increase step width to maintain stability. Despite showing greater step time variability (an indicator of gait instability) in OA, Malatesta et al. [8] did not observe a relation between step time variability and Cw, however they suggested this may be due to their relatively low sample size.

Furthermore, age-related changes in metabolic expensive responses due to instability is not evident in kinematic analyses [9]. The reason may be that the effect of lateral balance leads to adaptations that encourage greater stability without increasing the mechanical energy, such as increase of co-contractions of antagonist muscle. OA’s ability to actively control lateral stabilization during gait may decline due to progressive impairment of neuromuscular function

[3]. Therefore, to maintain lateral stabilization during gait, OA adopt stabilization strategies that increase co-contractions of antagonist muscles [9],[10],[17],[18].

4.3 Co-contractions of antagonist muscles

An increase in co-contraction in OA during gait may occur as a compensatory mechanism to increase joint stiffness and thereby enhance stability [9], [17]. This may be needed due to muscle weakness and stiffness in OA which makes it harder for them to recover after a trip or loss of stability. The increase of co-contractions of antagonist muscles, could result in higher Cw because the age-related increase in co-contractions of antagonist would require each agonist muscle to produce additional force, recruit a greater portion of muscle mass, and consume more energy to offset the opposing force of the antagonist muscles [9], [10], [17], [18]. According to Ortega and Farley [20], the increase in co-contractions of antagonist muscle would not appear in external work, i.e., propulsion of the body, since the coactivated antagonist could absorb it, as well as contraction of some antagonist leg muscles increases more rapidly with speed in OA than YA [9]. This may explain the higher Cw between OA and YA at different speeds.

Not all studies show a clear association between Cw and co-activation. For example, Peterson and Martin[10] shows that coactivation indicators for the thigh were not associated with Cw. Instead, OA showed significant correlation between shank and Cw. Mian et al. [9] also found that OA have a positive relation between the timing of lower extremity coactivation and Cw, but it was in relation to the time of coactivation in the thigh. The results of both studies were not fully compatible with each other. Despite that, the combination of thigh and shank and Cw [10] have significant correlation. Combined with similar result from other studies [8], [9], [10], [14], [17], [18], [19], [20], there is a suggestion that coactivation contributes to higher Cw that is observed in OA.

4.4 Mechanisms in walking behavior

There are different goals for maintaining normal gait, whether it is stability or maneuverability, the gait will find its assessment and intervention. Measurement methods tend to focus on the components of gait instead of the behavioral goal for walking. For instance, Dean et al. [14] focuses on stabilization, which might assess the gait variability, while Gaesser et al. [19] focuses on maneuverability, which only assess the cost of walking. OA may have adopted movement control strategies that were more maneuverable but less stable during conditions with uncertainty.

Furthermore, the result of higher Cw may therefore be a tradeoff between stability and maneuverability during a goal directed gait.

4.5 Physical activity

Although our studies describe the participants as relatively healthy, there is a lack of information about the participant's individual physical level, activity as well as anthropometric. A potential reason for the discrepancy between Mian et al [9] and Peterson and Martin [10] is a difference in the health and physical activity status of participants. Previous research has shown that resistance training may result in reductions in coactivation [23]. Mian et al. [9] investigated healthy community dwelling individuals, free from frailty, or signs of gait impairment, but did not report the participant's individual physical level. While Peterson and Martin [10] concerted effort was to recruit healthy, physically active OA that where free of any gait impairments, that most of them completed four or more exercise bouts per week. Thus, the differences and variation between daily physical activity and level between YA and OA, in our overview of studies, can affect the evaluation of Cw. In addition, this could also affect the evaluation, since some of the studies used participants that matched body mass and body composition in relation to the age [8], [10], [18], while others did not [9], [14],[17],[19],[20].

The simultaneous timing of muscular activation pattern between YA and OA, represented by coactivation in thigh, may be related to OA high levels of physical activity of the study [10]. Even with OA high levels of physical activity, compared to all the other studies. Cw was associated with higher levels of co-contractions of antagonist muscles. These results, along with the observed main effect of aging on the combination from thigh and shank show that physical activity level may not be such an important factor for higher Cw.

4.6 Aging

It is clear that aging is a process involving many factors and processes, thereby entangled is a suitable term for this complex change over time in which many factors are involved. Aging as a phenomenon is a physiological process, dynamic and irreversible, which occurs in the individual development of living organisms. Evolutionary theory assert that aging is not an adaptive trait but that many organismal functions are bound to fail with time, because none could have evolved to last indefinitely [24]. In such case, physical level and activity and other age-related factors in OA may not be necessary to question why Cw is higher. The physiological process of aging show that in the end, at different aspects of life, all humans suffer decline in function, which results in higher Cw with age regardless of environmental factors of living. This is defined as chronological age. What changes during this chronological aging is a far more difficult issue.

4.7 Methodological issues

Different limitation in study design and implementation of the different studies could give some constriction to interpretation of the results. Some of the studies, for instance Hortobágyi's [18] experimental protocol had its sole focus on muscle activation. Hortobágyi's et al. [18] interpretation of their result showed an impediment, since the studies measurements had an absence of multifactorial approach to measuring Cw. Even if Hortobágyi et al. [18] expressed muscle activation relative to maximal EMG activity, another limitation could however be that this was not done for oxygen uptake. Although it might not be detrimental for the findings, this still leaves us questioning the validity of the conclusions. Compared to the other 7 studies, there is a difference in how the measurements were calculated and conducted. The multifactorial way of measuring Cw, results in a complex way for the studies to conclude the many factors behind it. However, this doesn't necessarily mean that the results are not adequate, it is important to emphasize the complexity of the subject. But it is still a reason to believe that for future studies conducting this topic, it is beneficial to examine different and more supplementary variables in their testing and results, so it is easier to make a firm conclusion.

A problem which characterized all studies in experimental settings is the usage of treadmill while measuring Cw. A study performed by Schellenbach et al. [25] tested familiarization to treadmill walking versus overground walking. They conducted in their study that familiarization on treadmill walking is a necessity to provide reliable and valid measurements when subjects use treadmill as an instrument. Familiarization time of over 20 minutes is adequate for subjects to be familiar and make similar measurements between treadmill and overground walking. As seen in the studies, experimental methods of Dean et al. [14], Hortobágyi et al. [18], and Ortega and Farley [20] did not implement a familiarization test that lasted 20 min or more. Thus, their results could be inconclusive and not comparable to normal walking. Because it is unclear if treadmill walking and insufficient familiarization time is a confounding factor in the elevation of Cw. A suggestion for future studies is to address and to minimize the difference between treadmill walking and overground walking.

Gaesser et al. [19], compared to the other studies had a large sample size, which allowed them to examine differences not only between YA and OA, but also to decide if the age-related differences existed within a substantial number of adults. Larger samples provide statistically secure estimates. This is shown by Gaesser et al. [19] who divided the OA participant in three age sub-groups and found no statistically significant differences in Cw between YA and OA (60-69y), only statistically significant differences in OA (≥70y). The diversity between ages in the studies is large, as the youngest participant in the studies was 18y and the oldest was 86y. The large age spread between the studies that only examined the two age groups can influence the effect of Cw in the different aged individuals.

5. Conclusion

All studies investigated in this thesis showed that walking, at and around the individuals preferred speed, required higher Cw in the OA compared to YA. The studies suggest that the age-related increase in co-contractions of antagonist muscle activation may explain higher Cw in OA. But changes in chronological aging in humans is inevitable. Due to the complex process of aging OA probably will have a higher Cw than YA, regardless of the type of physical activity level or other singular age-related factors.

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